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Article

Optimization of preventive maintenance in the design of photovoltaic plants

Optimización del mantenimiento preventivo en el diseño de plantas fotovoltaicas

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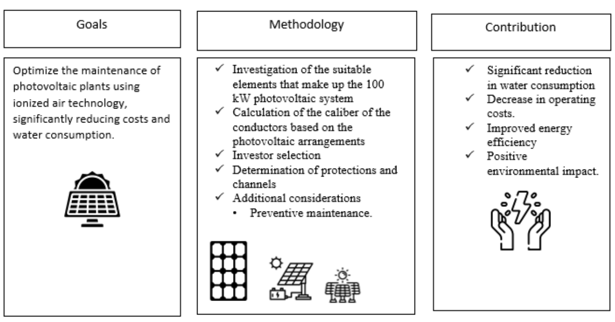
Abstract

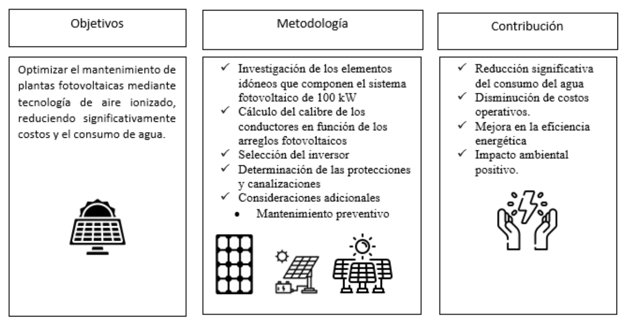
Two of the biggest problems worldwide are electrical energy and water, in this context the use of photovoltaic systems for the generation of electrical energy is increasingly profitable due to the constant reduction of prices in terms of the dollar watt and that supports the solution to the problem of energy supply at increasingly affordable prices. In this same scenario we have a reduction in CO2 emissions, contributing to the reduction of greenhouse gases, supporting the Kyoto protocol and the Paris agreement. On the other hand, the incorporation of ionized air for cleaning the photovoltaic modules allows the use of natural and demineralized water to be reduced to levels of around 98%, which allows us to be on par in saving solutions for this vital liquid.



Energy, Solar, Panel

Resumen

Dos de los mayores problemas a nivel mundial es la energía eléctrica y el agua, bajo este contexto la utilización de los sistemas fotovoltaicos para la generación de energía eléctrica es cada vez más rentable por la constante reducción de precios en cuanto a la relación dólar watt y que apoya en la solución a la problemática de abastecimiento energético a precios cada vez más asequibles. En este mismo escenario tenemos una reducción de las emisiones de CO2, contribuyendo a la reducción de gases de efecto invernadero, apoyando el protocolo de Kioto y el acuerdo de París. Por otro lado, la incorporación de aire ionizado para la limpieza de los módulos fotovoltaicos permite reducir a niveles de alrededor de 98% el uso del agua natural y desmineralizada, lo que permite estar a la par en las soluciones de ahorro de este vital líquido.



Energía, Solar, Panel

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Introduction

In the context of an increasingly environmentally conscious world and businesses in constant search for cost reduction when operating, sustainable energy sources have gained great importance. For this reason, the design and subsequent optimisation of the 100 kW photovoltaic plant is described throughout this article. The main objective of the installation is to generate clean energy and reduce the carbon footprint. The following details the approach taken in the electrical design of the installation, from the choice of components to the calculations of conductors and protections and how automation is implemented to improve efficiency and reduce risks. The use of renewable energy in a plant environment can give the company the competitive advantage of reducing reliance on energy from traditional sources and the risks associated with the costs involved. The plant in question is just one example of how sustainable practices can go hand in hand with efficiency and responsibility.

Theoretical framework

Fundamentals of Electrical Design in Photovoltaic Plants

The electrical design of a PV plant is fundamental to ensure that the system operates in an efficient and stable manner. This process involves the choice and layout of solar panels, inverters, wiring and protection systems, each with a crucial role in the overall performance of the system.

Solar panels are a fundamental part of the PV system. These panels convert sunlight into direct current (DC). The efficiency of the panels depends on the quality of their materials and the design of the solar cells. In addition, the way the panels are oriented and tilted affects how much energy they can capture. For example, an incorrect tilt angle can significantly reduce energy production (Chen & Huang, 2020).

Inverters are another key component. They convert the direct current generated by the panels into alternating current (AC), which is used in the electricity grid. There are several types of inverters, each with its advantages and disadvantages.

Central inverters, for example, are ideal for large installations because they handle large volumes of power economically (Baker & Perez, 2022). String inverters, which connect several panels in series, offer more flexibility and may be better for systems with varied configurations. Finally, microinverters connect to each panel individually and can be useful in installations where there are shading issues (Castro & Figueroa, 2023).

Optimising photovoltaic performance

Optimising the performance of photovoltaic systems is crucial to get the most out of solar energy. To achieve this, several factors can be adjusted, such as the tilt angle of the panels, using sun-following systems and reducing shading (Bertoni & Ferrara, 2021). The angle at which the panels are placed should be adapted to the latitude and seasons of the year to capture as much solar radiation as possible.

Sun-tracking systems, which adjust the orientation of the panels throughout the day, can increase energy production compared to fixed systems. Although these systems can be more expensive and require more maintenance (González & Martínez, 2023), they can justify their additional cost with the increase in energy production. In addition, monitoring technologies allow system performance to be monitored in real time, making it easier to identify and solve problems that may affect efficiency (Kumar & Singh, 2023).

Inverter technologies and their impact

Choosing the right inverter technology can make a big difference in the efficiency of a PV system. Central inverters, which group the output of several panels at a single point, are generally the most economical option for large installations (Hassan & Ahmed, 2022).

On the other hand, string inverters allow more flexibility and can be more efficient in systems with various configurations (Kim & Lee, 2021) [VIII]. Microinverters, which optimise each panel individually, are ideal for installations with shading or uneven tilt problems (Castro & Figueroa, 2023).

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Wiring and protection design

The wiring in a PV plant must be well designed to avoid energy losses and ensure safety. The cables must be robust enough to handle the current generated by the panels without overheating (Davis & Jones, 2022). In addition, it is important to consider the distance between the panels and the inverter and how environmental conditions can affect the cables.

Protection of the system is essential to avoid damage. Protective devices, such as circuit breakers and fuses, should be used to prevent overloads and short circuits. These devices must be suitable for the specific system to ensure that everything works safely and efficiently (Fernandez & Lopez, 2021).

Performance Evaluation and Maintenance

In order to keep a PV plant in optimal condition, continuous performance evaluation and preventive maintenance is crucial. Modern systems make it possible to monitor energy production in real time and detect potential problems before they become serious problems (López & Moreno, 2021).

Preventive maintenance, which includes cleaning panels and checking connections, can extend the life of the system and ensure that it continues to operate at its maximum capacity (Smith & Wang, 2022).

Methodology

Investigation of the Suitable Elements of the 100 kW Photovoltaic System

The first step in developing an efficient PV system is to carefully select the components that optimise the energy production, durability and safety of the system. The main elements of a 100 kW PV system are solar panels, inverters, conductors, mounting systems and protection devices.

Solar Panels

The solar panels are the heart of the system, as they convert solar radiation into electricity. For a 100 kW system, it is essential to select highly efficient and durable modules.

Currently, panels typically have an output of between 320 and 450 W per module. To reach 100 kW, between 222 and 312 modules are required, depending on their capacity (100 kW / 450 W ≈ 222 modules).

In addition to the power, it is important to consider the efficiency of the modules. Panels with efficiencies above 18% allow for a reduction in the number of modules and optimisation of the available installation space. Monocrystalline modules are commonly preferred for their higher efficiency, especially in low irradiation conditions.

Inverters

Inverters are essential for converting the direct current (DC) generated by the panels into alternating current (AC), which is used in power grids. The selection of a suitable inverter is key to maximising efficiency and ensuring the correct operation of the system under various conditions.

Mounting systems

Support structures should be selected considering whether the installation will be roof or ground mounted, the climatic conditions of the site and the optimal orientation to maximise solar radiation collection. Structures made of corrosion resistant materials, such as galvanised steel or aluminium, are recommended to ensure the longevity of the system.

Electrical protections

The system must have adequate safeguards to prevent damage to components and ensure safety. This includes overvoltage, short-circuit and overload protection, as well as a grounding system that protects against electric shock and complies with safety regulations.

Trunking and conductors

The design must provide for adequate conduits and conductors for power transmission. Selecting the correct conductors is essential to minimise voltage drop losses and ensure the safety of the system. Conduits must protect the conductors from mechanical damage and adverse environmental conditions.

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Calculating conductor sizing for photovoltaic arrangements

The calculation of the conductor size is crucial to ensure the efficiency and safety of the system. The size of the conductors depends on the current, the distance, the allowable voltage drop and the ambient temperature.

Current determination

To calculate the conductor size, the maximum current must first be determined. This current is calculated by dividing the system power by the operating voltage. For a 100 kW system operating at 1000 V, the current would be: $I=(100{,}000\ W/1000\ V)=100\ A$.

Size selection according to voltage drop

The conductor size is selected by considering the voltage drop, which normally should not exceed 3% of the nominal voltage. The formula for voltage drop is: $Vd=(2 \cdot I \cdot L \cdot R)/A$ where Vd is the voltage drop, I is the current, L is the conductor length, R is the resistivity of the material, and A is the conductor cross-section. The rating is adjusted to keep the voltage drop within the allowable limits.

Inverter Selection

Correct inverter selection is vital to ensure efficient operation. The inverter must handle the power generated by the panels and convert it into alternating current (AC).

Inverter Types

There are three main types of inverters:

1. Central inverters: Suitable for large installations.

2. String inverters: Connected to groups of modules, they offer flexibility.

3. Microinverters: These are placed in each panel and optimise individual production, more common in small installations.

Selection Criteria

The inverter must be capable of handling at least 100 kW, preferably with a 10% margin to cover production peaks. Its input voltage should match that of the PV arrays. In addition, it is advisable to select inverters with an efficiency of more than 97% to minimise losses.

Determination of the Protections and Trunking

It is necessary to select adequate protection devices and design conduits that comply with electrical safety regulations.

Electrical Protections

Systems require overvoltage, overload and short-circuit protection, including circuit breakers, fuses and transient surge protectors.

Trunking

Conduits must protect conductors from damage and comply with local regulations, such as the Mexican Official Standard NOM-001-SEDE-2012. In outdoor installations, the use of metallic or PVC conduits is recommended, depending on environmental conditions.

Additional Considerations

System Monitoring and Control

The integration of automated monitoring systems is recommended to measure real-time energy production, operating conditions, and detect faults.

Some software options used for the design of 100 kW PV plants, highlighting their main features, benefits and applications:

Comparative Analysis

PVSyst is one of the most widely used software for PV system design due to its accurate and detailed simulation capabilities.

Benefits:

- Provides comprehensive analyses of annual energy production.

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- Simulates losses due to factors such as shading, temperature and internal resistances.

- Useful for sizing both small and large systems.

Limitations: Interface can be complex for novice users.

Ideal Use: Small and large-scale projects that require accurate simulation of long-term performance.

Helioscope this software excels in ease of use and speed of design, allowing you to simulate environmental conditions in real time.

Benefits:

- Fast simulations with real-time modelling.

- Calculate shading and optimise panel placement.

- Includes financial analysis.

Limitations: Lacks some of the advanced detail in electrical system modelling that PVSyst offers.

Ideal Use: Medium to large projects requiring fast simulations and detailed design and shading analysis.

SolarEdge Designer this software is specific to systems using SolarEdge inverters and optimisers, making it ideal when using their equipment.

Benefits:

- Optimises system efficiency for installations with SolarEdge equipment.

- Detailed wiring and shading loss simulations.

Limitations: Limited to systems with SolarEdge technology, which restricts its use to these devices.

Ideal Use: Projects using the SolarEdge brand, especially in commercial and industrial installations.

AutoCAD although not a specific software for PV design, is essential in the technical and physical planning of the plant.

Benefits:

- High accuracy in planning physical and electrical layouts.

- Integration with other design and simulation systems.

Limitations: Does not offer energy simulations or loss analysis.

Ideal Use: Projects where detailed physical design is essential, complementing other simulation software.

SAM (System Advisor Model) is a software developed by NREL that combines energy analysis with financial analysis, based on meteorological data.

Benefits:

- Performs energy production simulations based on historical weather data.

- Integrates financial analysis to assess the economic viability of the project.

Limitations: May not be as detailed in simulations of shading or voltage drops as other programs.

Ideal Use: Projects that require financial feasibility assessment along with energy analysis.

Preventive maintenance

The system should include a preventive maintenance plan to prolong the life of the components and ensure their continued operation. This includes cleaning of panels, inspection of connections and calibration of monitoring systems.

Maintenance of solar panels is essential to ensure their optimal performance and to prolong their lifetime. There are different methods to clean them, the most common of which include the use of water and ionised air.

1. Water cleaning

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Water cleaning is one of the most traditional and effective techniques, especially in areas with significant accumulation of dust, dirt, or organic debris. Some considerations are:

Demineralised or distilled water: It is advisable to use mineral-free water to avoid staining by mineral residues that can reduce the efficiency of the panels.

Automated cleaning systems: These systems use pressurised water jets to clean the panels, minimising the risk of damage and reducing manual effort.

Frequency: Water cleaning is usually carried out once or twice a year, depending on the environment. In arid or highly polluted areas, more frequent cleaning may be required.

Caution with chemicals: The use of aggressive chemicals that may damage the surface of the panels or affect the anti-reflective coating should be avoided.

2. Cleaning with Ionised Air

Ionised air is an advanced technology that is being used for cleaning solar panels, especially in areas where access to water is limited or expensive. This method involves the use of ion-charged air, which effectively removes dust and other contaminants without direct physical contact. Advantages include:

No water use: Ideal for areas where water is a scarce resource.

Efficiency without residue: Ionised air removes particles without leaving residue, preventing staining or corrosion.

Less wear and tear: By not using water or brushes, there is less risk of damage to panels or scratches to their surface.

Automation: This method can be easily automated, with robots or devices installed that clean the panels on a continuous or scheduled basis.

Comparison of methods

Traditional Method (Demineralised Water and Vinegar).

The traditional method of cleaning solar panels is based on the use of demineralised water and, in some cases, a mixture of white vinegar with calcium bicarbonate to remove mineral deposits. The main costs associated with this process are:

Demineralised water: 20 litres cost between 240 and 280 pesos, which translates into a considerable expense if frequent cleaning is required. When water pipes are used (19,000 litres at 6,000 pesos), the monthly cost amounts to 24,000 pesos, which implies an annual cost of 78,000 pesos for water alone.

Labour: To carry out maintenance, specialised personnel are required, the annual cost of which, considering two workers with a salary of 2,000 pesos per week plus benefits, amounts to 208,000 pesos.

Vinegar and bicarbonate: This compound is used twice a year to remove carbonate incrustations on the panels. This involves an additional 134,500 pesos per year in white vinegar (1,000 litres).

This method is not only more costly in terms of inputs and labour, but also has a significant environmental impact due to the high water usage.

Innovative Method (Ionised Air)

On the other hand, the use of ionised air represents a modern and more efficient alternative, with the following benefits:

Ionisation kit: This kit, which includes a gun and compressor, has an initial cost of just 827 pesos. In addition, it does not require the constant use of water, except in specific cases such as cleaning bird droppings.

Water savings: With ionised air, water use can be reduced by up to 98%, which not only reduces operating costs, but also the environmental impact. Annual water savings are estimated at 78,000 pesos.

Reduced chemical usage: The need to remove carbonate scale is no longer a constant problem, saving an additional 134,500 pesos per year on products such as vinegar and bicarbonate.

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Results

When comparing the two methods, the use of ionised air shows clear advantages. Not only does this system significantly reduce operating costs (more than 200,000 pesos per year in water and product savings), but it also improves the efficiency of the panels by keeping them clean continuously and without complicated procedures.

In terms of environmental impact, the reduction of water use (up to 98%) is a substantial benefit, especially in areas where this resource is scarce. In addition, the reduced use of chemicals reduces the ecological footprint of the maintenance process.

From a labour and safety perspective, the ionised air method is also favourable as it requires less direct human intervention, which increases worker safety by avoiding exposure to chemicals and water-intensive tasks. In addition, this system allows for greater optimisation of maintenance time, being faster and less intrusive than the traditional method.

Conclusions

By using the 499 KW photovoltaic installation of the Technological University of Chihuahua as a test laboratory, it could be seen that the use of ionised air for cleaning purposes was more efficient in that the blowing is carried out every four weeks and there is much less dispersion of solids or particles adhered to the surface of the module than using water for cleaning.

We were able to observe that the ionised air does not leave residues as the water we use does, as it is well water extracted at a depth of 120 metres, dragging with it multiple particles including calcium carbonate. As it is well water, the hardness of the water is high, due to the large amount of magnesium and calcium present in it, which results in these residues becoming embedded in the surface of the photovoltaic module, causing an attenuation of the reception of solar energy and a drop in the module's efficiency. On the other hand, if demineralised water is used, the cost of preventive maintenance increases significantly.

As the State of Chihuahua is a desert region, very arid, with constant droughts that last between 8 and 11 years and therefore the large amount of dust that exists in the environment is constantly impregnating the surface of the photovoltaic modules, preventive maintenance is more recurrent, about every 4 weeks and in the months of February to April, this is every 3 weeks, due to the windy season. The use of ionised air reduced maintenance costs, eliminating up to 98% of well water, not to mention demineralised water, which is completely eliminated, as ionised air does not leave residues that attenuate the reception of sunlight. Derived from the above statements, already purchased at the photovoltaic plant of the Technological University of Chihuahua, it is concluded that, in terms of preventive maintenance cost savings, it is better to use ionised air.

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